AN EXPERIMENTAL STUDY ON THE DYNAMICS OF ADSORBED NATURAL GAS CHARGE ON ACTIVATED CARBON COLUMN

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Abstract. *This work aims at analyzing dynamic sorption experimentally during the charge process of natural gas on to an adsorptive column filled out with activated carbon. The column represents an automotive vehicle tank element that allows the circulation of the gas through an external heat exchanger needed for the dissipation of the heat of adsorption that comes from the porous bed during the gas loading exothermic process. An experimental bench was set up and equipped to allow us to obtain thermo-grams from inside the column, to measure any pressure drop and the gas mass flow. The experimental results revealed that depending on the applied flow, the time of load of the column varies from 50 to 250 seconds. These time measures have been considered satisfactory for fast loading conditions. Finally, the results have also shown that the speed of the gas flow can vary significantly inside the column, depending on the pressure and on the applied flow.*

Keywords*: adsorbed natural gas, fast load, activated carbon*

1. INTRODUCTION

In the search for new and better ways of developing clean fuels, natural gas (NG) was considered a reasonable alternative as a fuel for transportation. (Pupier *et al.* 2004).

There are three different methods for natural gas storage: liquefied natural gas (LNG), compressed natural gas (CNG) and adsorbed natural gas (ANG). According Salehi *et al.* (2007), in the case of natural gas vehicles and transport means, high pressure are required, approximately 20 MPa. The high cost of high-pressure cylinders and facilities limit the practical use of CNG. Furthermore, the system needs expensive LNG facilities of cryogenic, which makes it economically unfeasible in vehicle applications. Among these, the ANG is a technology in which natural gas is adsorbed by a porous adsorbent such as activated carbon at relatively low pressure of 4 MPa. It also allows flexibility in the configuration of storage cylinders and reduces total cost: from manufacturing to installation. (Ridha *et al.* 2007).

The possibility of a ANG storage system has been actively researched in recent years. However, control effectively the heating effect resulting from the heat of adsorption in the ANG loading process is still today a bottleneck for the development of vehicles powered by storage ANG (Yang *et al.* 2004). This heating effect influences the loading time of ANG storage system directly, due to the exothermic feature of the process.

Santos, in 2005, proposed an alternative configuration for ANG storage in a multitubular tank filled with activated carbon. The system configuration consists of non-adsorbed gas recirculation between the tank and an external heat exchanger to remove the heat generated in the sorption process and reduce the loading time.

This paper aims to examine experimentally the dynamic loading of an alternative storage system of adsorbed natural gas on a multitubular tank open to atmosphere under similar conditions and configuration of the system with recirculation proposed by Santos in 2005.

2. THEORETICAL RATIONALE

Adsorption is a phenomenon that occurs when a solid surface (adsorbent) is exposed to a liquid fluid or gaseous (adsorptive). A force field is generated by electrostatic imbalance, due to the irregularity of the solid surface, at the molecular level. Depending on the type of forces that govern the phenomenon, it can be classified as physical or chemical adsorption.

Physical adsorption is due to an intermolecular forces system of Van der Waals and electrostatic forces that generate attraction and repulsion power between the adsorbent surface and the molecule of the adsorbato.

Chemical adsorption results from a strong interaction between the adsorptive and adsorbent. Here, there are ionic links between the molecules of adsorbent and the adsorbato ones.

The substance accumulated in the porous medium (adsorbent) is defined as adsorbato, since the material is usually found in gas phase and is able to be adsorbed it is defined as adsorptive (SOUZA, 2005). This classification is illustrated in Figure 2.1.

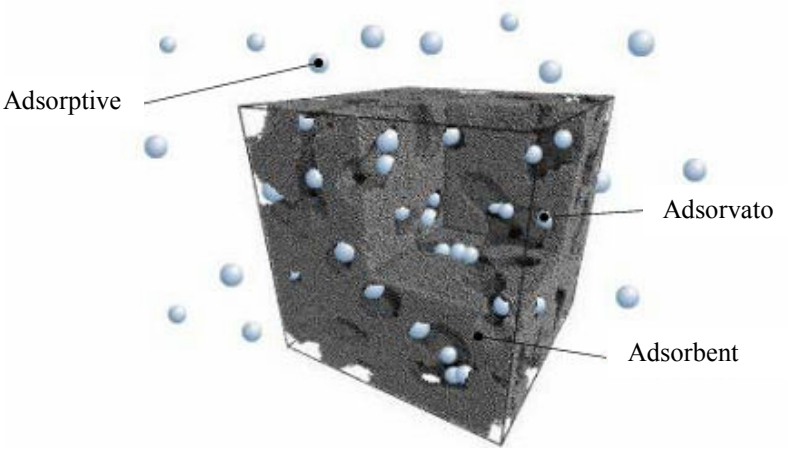

Figure 2.1 - Schematic of a particle of porous solid with adsorbed molecules (adsorbato) and not adsorbed (adsorptive) adapted by Souza (2005)

3. EXPERIMENTAL SECTION

3.1. General Schedule

A trial bench was instrumented and mounted. It consists of a multitubular tank with activated carbon, which is referred in this work as adsorption column, according to Figure 3.1.

The adsorbent employed in the experiment was the activated carbon from Westevaco (WV1050) and natural gas, the adsorptive.

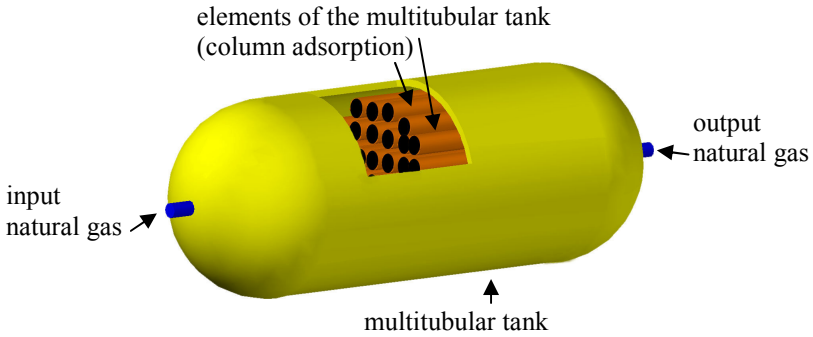

Figure 3.1 - Multitubular tank

The adsorption column was made from copper, with mesh filters at the ends and four smugglers to wires passing along the column. Platinum sensors were positioned at the center of the column to obtain thermograms within the column. A digital scale, a digital hot wire anemometer and a pressure-reducing valve was used to record the data, respectively, the mass of activated carbon and gas, to measure the velocity at the outlet of the column and reduce the pressure of the cylinder supply gas. As illustrate the Figure 2.2.

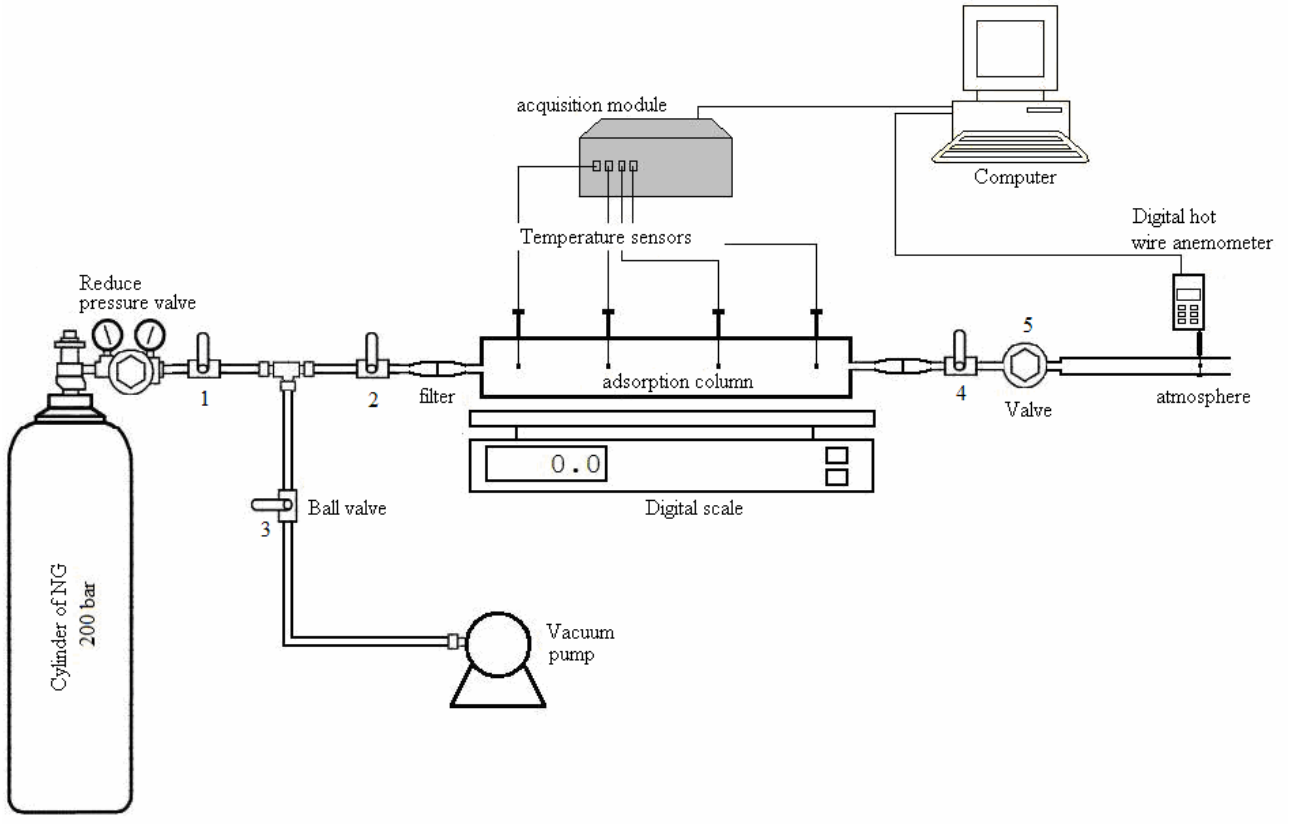

Figure 2.2 - Setting the bench trial.

3.2. Experimental Procedure

Initially, the mass of the empty column and activated carbon were measured with a digital scale. The difference between measurements results in activated carbon sample mass. After these procedures, the column is mounted in the trial bench.

The vacuum pump had been in operation for about 30 minutes, holding a vacuum of 1.33 mbar x103 in the activated carbon bed to cause the detachment of gases, possibly, adsorbed internally by the activated carbon grains. After the 30 minutes, the ball valve 3 is closed and the pump is turned off.

The reduce pressure valve is regulated to a desired pressure, the ball valve 1 is open and the scale is set at zero point (tare). Soon after, the ball valves 2 and 4 are open. Before, the valve 5 is partially opened so that the adsorptive strikes, in the output, a random speed. In this way, we can establish a ranking: low speed (in the range 0.8 to 2.5 m / s) and high (in the range of 2, 6 to 8.4m/s).

The data recorded by the acquisition module, digital hot wire anemometer and digital scale, were stored in a computer. Thus, the adsorption is initiated in the column. The process is repeated with each change of pressure and speed.

Analysis were performed without monitoring the balance. Therefore the measurement of the mass of the adsorbato was made after the procedure, removing the column from the bench with the valves 2 and 4 closed.

4. RESULTS AND DISCUSSION

Natural gas was loaded in the column for adsorption under the experimental procedure described above. Figure 4.1a shows the temperature measured by the sensors, during the loading cycle. It can be observed that the obtained loading time is approximately 5 minutes. It is considered a short time because Neto *et al.* (2005) recorded a loading time greater than 300 minutes (see Figure 4.1b) in a cylinder filled with activated carbon, as illustrated in Figure 4.2.

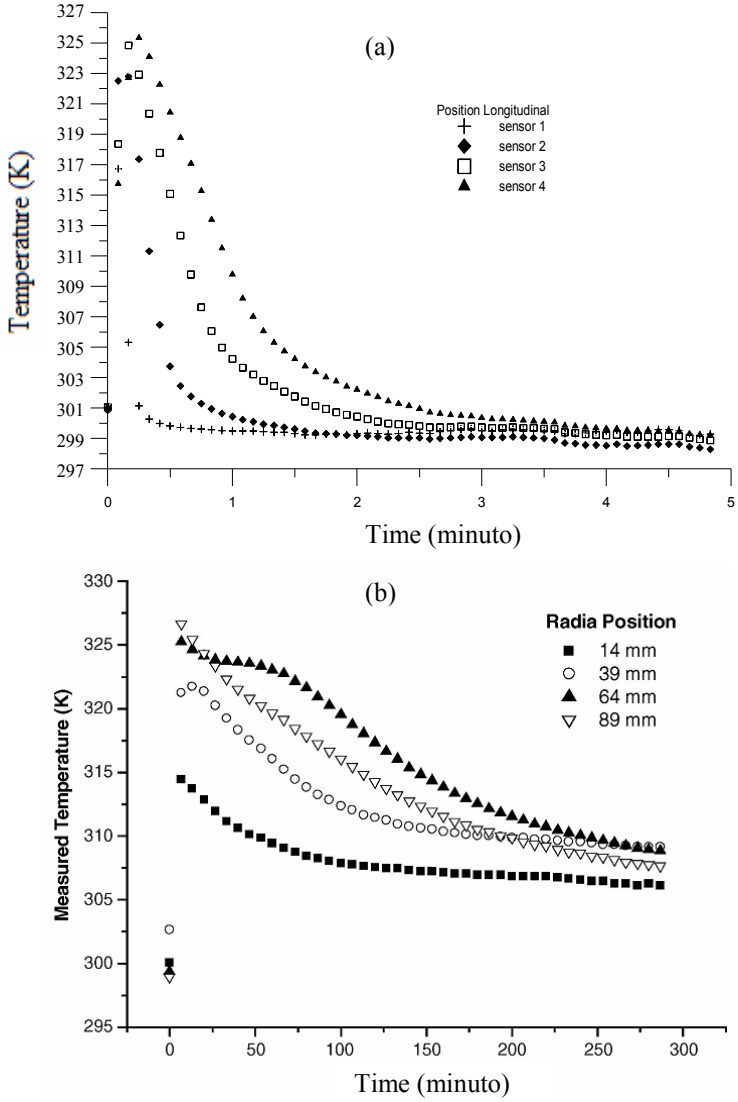

Figure 4.1 - (a) data of temperature for the loading process as a time function. (a) data obtained from this experimental work. (b) data obtained from Neto *et al.* (2005).

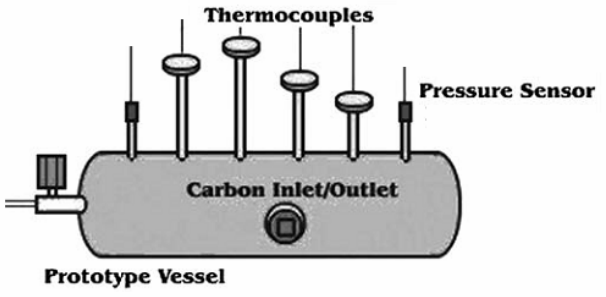

Figura 4.2 - Experimental setup of vessel prototype. Adapted by Cicero H. T. Andrade.
Source: Neto *et al.* (2005)

The Figure 4.3 shows the velocity profiles at the outlet of the column against time, with input pressure equal to 5 bar. It can be observed that the output speed varies with increasing flow velocity at the bed. This can be explained by flow in solid pellets (flow in porous media). At the time of fluid particles transfer, total losses are given by the sum of the frictional drag film loss and kinetic energy loss. For low speed flow, kinetic energy loss is smaller than the drag loss, therefore this flow can be expressed by the load loss (a pressure decrease) as a function of permeability, roughness, density, viscosity and superficial velocity, described by the equation of Ergün, Eq(1). (Nield and Bejan, 2006, p12).

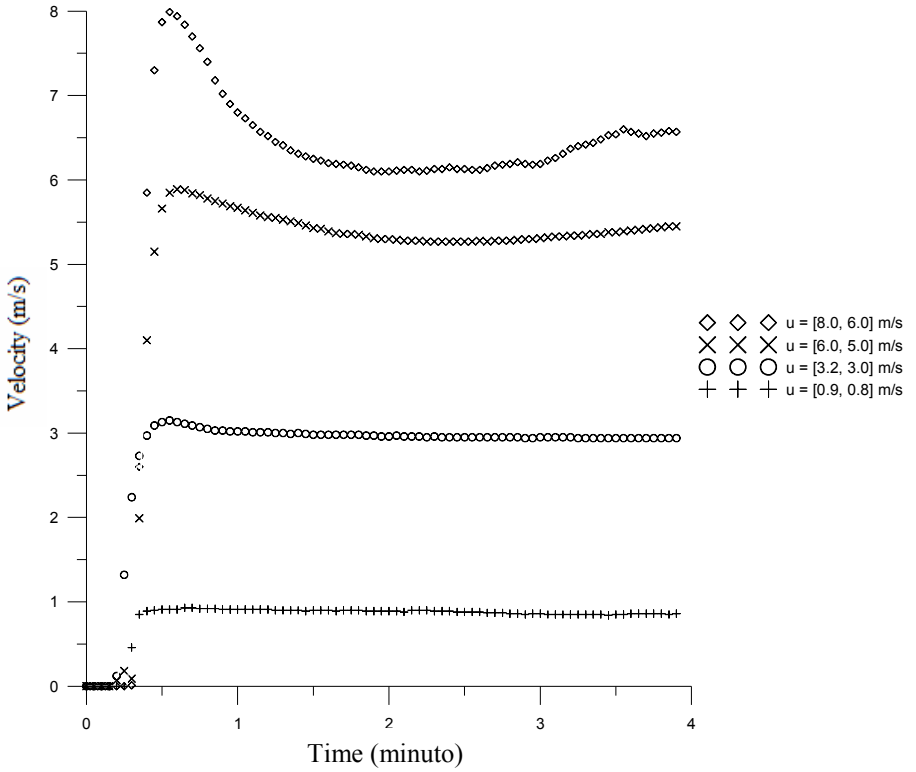

Figure 4.3 – Velocity profile at the exit of the adsorption column.

$$\Delta P = \left(\frac{150 \cdot \mu \cdot L \cdot V}{D_p^2} \right) \cdot \frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75 \cdot \left(\frac{L \cdot V^2 \cdot \rho_f}{D_p} \right) \cdot \frac{(1-\varepsilon)}{\varepsilon^3} \tag{1}$$

Where:

ΔP	Pressure Drop (Pa)
D_p	Diameter of particle (m)
L	Length of column (m)
V	Velocity of the fluid (m/s)
ε	Porosity of the bed
ρ_f	Density of fluid (kg/m^3)
μ	Viscosity of the fluid (kg/m s)

The first term of Eq (1) are the losses by surface friction of the fluid with the solid particles and the second term are kinetic losses caused by changes of direction, expansions and contractions within the bed.

The increased speed of the dynamics of fluid flow allows the reordering of the particles in order to offer less resistance to moving the small and tortuous channels in the porous bed. However, for high speed flow, the kinetic energy loss is greater than load loss, resulting in the adsorbent transport with the adsorptive.

4. CONCLUSION

The results obtained in this work indicated that the configuration of a natural adsorptive gas storage system in opened column is very efficient in loading time (about 5 minutes), showing a shorter time than the closed column system with saturation time over 300 minutes in the bed. This high efficiency is due to the forced convection effect between the adsorbent and the gas that flows in the bed, promoting a rapid dissipation of generated heat in the adsorption process of loading.

5. REFERENCES

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